Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams EPA 841-B-06-002

Chapter 1 Design of the Wadeable Streams Assessment

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Why focus on wadeable streams?

Like the network of blood vessels that supply life-giving oxygen and nutrients to all parts of our bodies, streams and rivers form a network that carries essential water to all parts of the country. The human body has far more small capillaries than large, major arteries and veins; similarly, only a few U.S. rivers span large portions of the country (e.g., Mississippi, Missouri, or Columbia rivers). Most of our nation's waterways are much smaller stream and river systems that form an intimate linkage between land and water.

This WSA addresses these smaller systems, which ecologists often refer to as "wadeable" because they are small and shallow enough to adequately sample without a boat. Almost every state, university, federal agency, and volunteer group involved in water quality monitoring has experience sampling these smaller flowing waters; therefore, a wide-range of expertise was available for this nationwide monitoring effort.

About 90% of perennial stream and river miles in the United States are small, wadeable streams. Stream and river ecologists commonly use the term Strahler stream order to refer to stream size, and wadeable streams fall into the 1st through 5th order range (Figure 1-1). First-order streams are the headwaters of a river, where the life of a river begins; as streams join one another, their stream order increases. It is important to note that many 1storder streams, particularly those located in the western United States, do not flow continuously. These intermittent or ephemeral streams were not included in this WSA because we do not yet have well-developed indicators to assess these waterbodies. At the other end of the range are those 4th and 5th order rivers and streams that are too deep for wadeable sampling methods. These waterbodies will be included in a future survey of non-wadeable rivers.

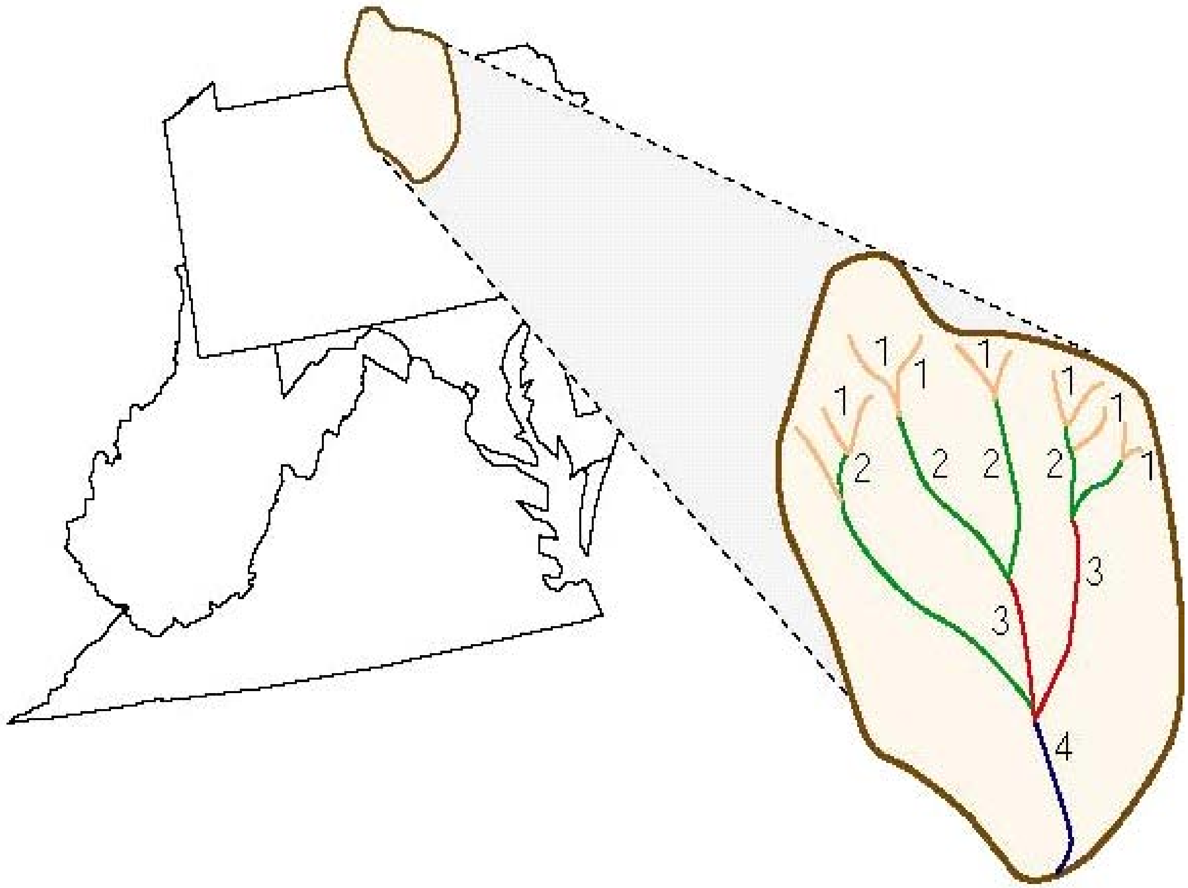


Figure 1-1. Strahler stream order diagram.

Stream size is categorized by Strahler stream order, demonstrated here for a watershed. The confluence (joining) of two 1st order streams forms a 2nd order stream; the confluence of two 2nd order streams forms a 3rd order stream.

Stream order (stream size) affects a stream's natural characteristics, including the biological communities that live in the stream, such as fish and invertebrates. Very small 1storder and 2nd order streams are often quite clear and narrow and are frequently shaded by the grasses, shrubs, and trees that grow along the stream bank. The food base (e.g., leaves and terrestrial insects) for these streams originates from the stream banks. These foods tend to dominate the ecology of these streams, together with algae that attach to rocks and wood, aquatic insects adapted to shredding leaves and scraping algae, and small fish that feed on these organisms. In contrast, larger 6th to 7th order rivers typically appear muddy because their flow carries accumulated sediments downstream. These rivers are wide enough that the canopy cover along their banks only shades a narrow margin of water along the river's edge. The food base for these waterbodies shifts towards in-stream sources, such as algae, downstream drift of small organisms, and deposition of fine detritus. Although the aquatic communities of these large rivers include insects and algae, larger rivers are dominated by insects adapted to filtering and gathering fine organic particles and larger fish that are omnivorous (feeding on plants and animals) and/or piscivorous (feeding on smaller fish) (Figure 1-2).

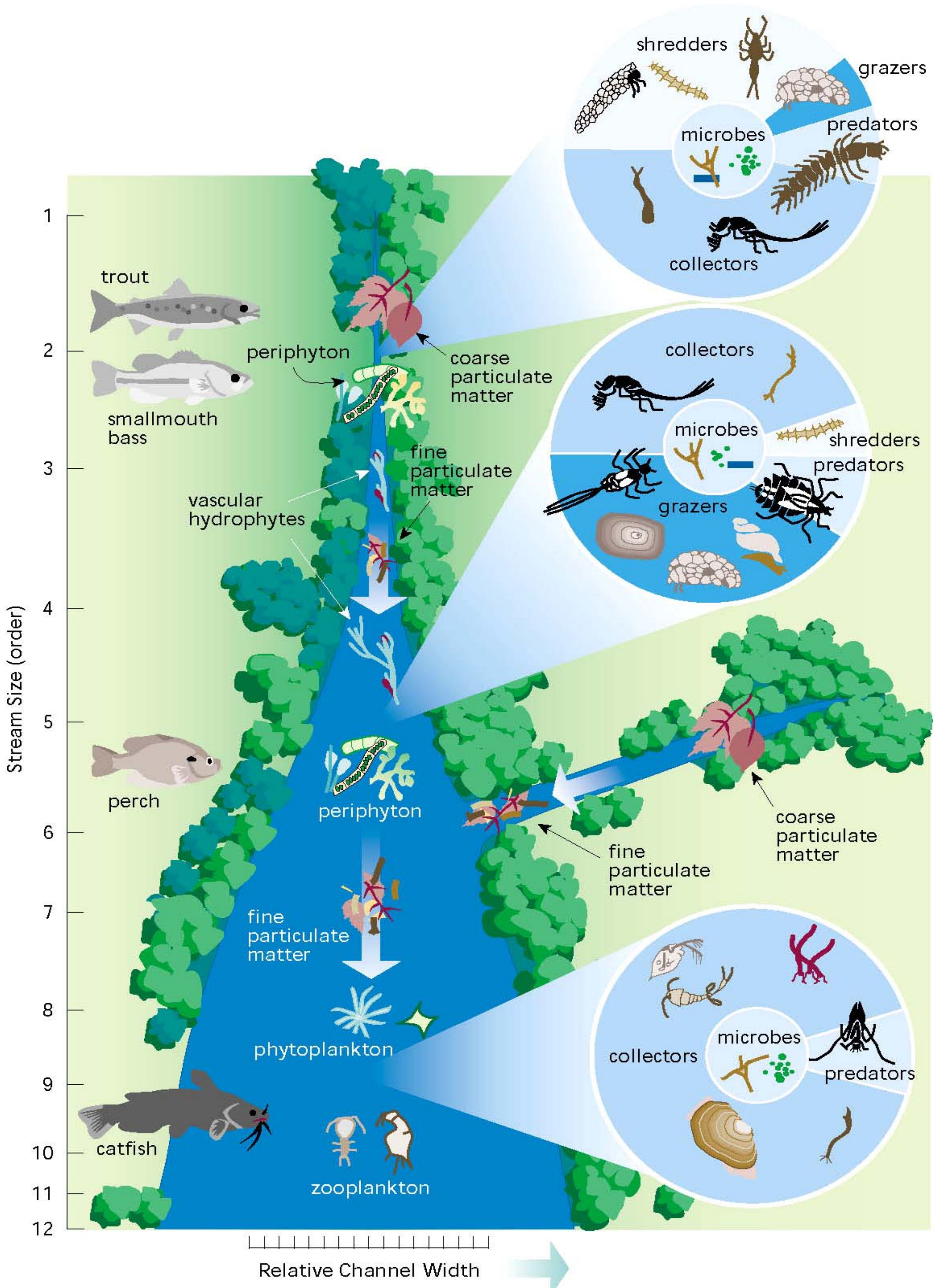


Figure 1-2. Stream characteristics change as the stream's size or stream order increases.

What area does the WSA cover?

This report covers the wadeable streams of the conterminous United States, or lower 48 states (Figure 1-3). This area covers 3,007,436 square miles (mi^2) and includes private, state, tribal, and federal land. Although not included in this WSA, initial stream-sampling projects outside the conterminous United States have begun and will be included in future assessments. For example, scientists in Alaska sampled streams in the Tanana River Basin (a subbasin to the Yukon River) during 2004 and 2005, and they expect to report their results in the summer of 2006. Guam has begun implementation of a stream survey, and Puerto Rico is developing indicators for assessing the condition of its tropical streams. In addition, the State of Hawaii will begin stream sampling on the island of Oahu in 2006.

Figure 1-3. Major rivers and streams of the United States.

Major rivers of the United States comprise only 10% of the length of flowing waters. Wadeable streams and rivers make up 90% of the length of the nation's flowing waters.

State political boundaries offer few insights into the true nature of the features that mold our streams and rivers. The most fundamental trait that defines our waters is annual precipitation (Figure 1-4). On either side of the 100th longitude that runs from west Texas through North Dakota, a sharp change occurs where precipitation falls plentifully to the east but sparsely to the west. (The high mountains of the West and the Pacific coast are exceptions to the general scarcity of water in the West.) The east-west divide in moisture has not only shaped the character of these waters, but also how we use them, how we value them, and even the legal system with which we manage their allocation. A second divide that defines the nature of our rivers and streams is the north-south gradient in temperature.

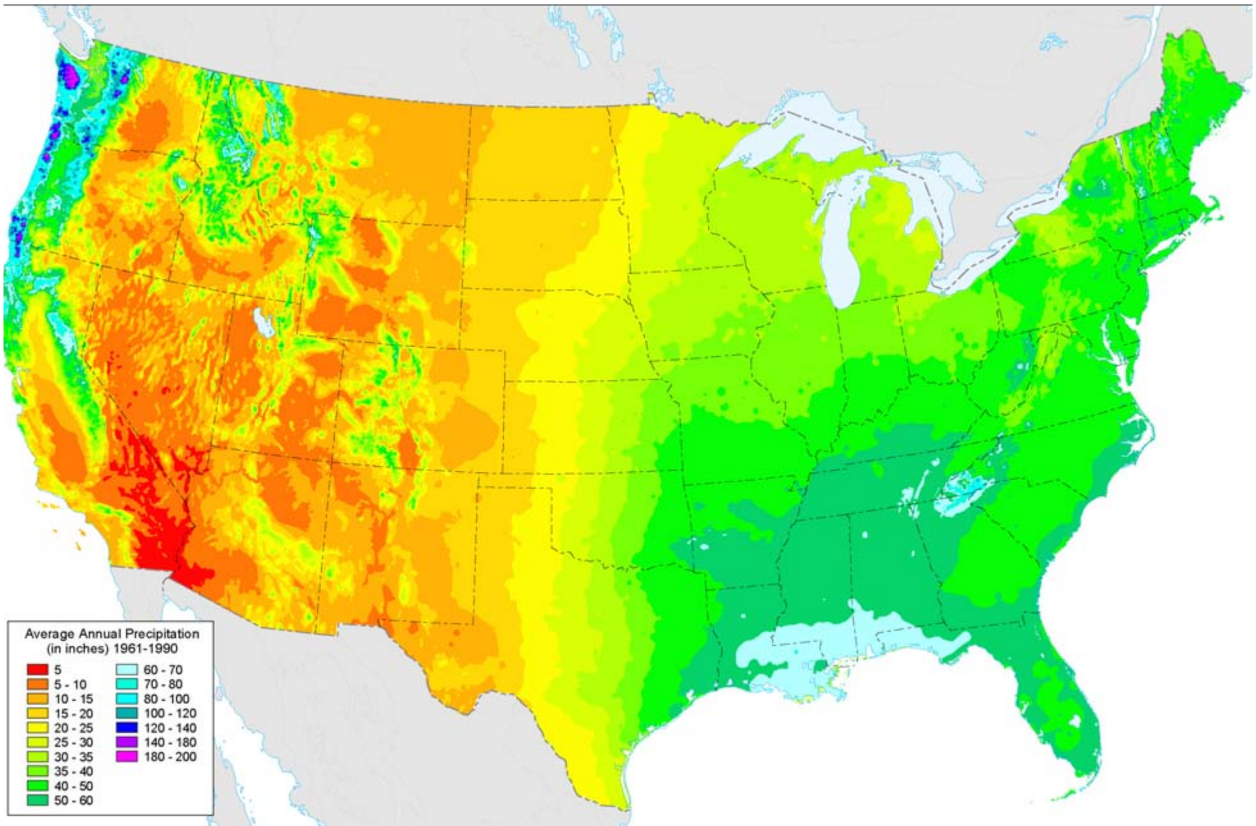


Figure 1-4. Average annual precipitation of the United States.

The 100th meridian runs from Texas north through North Dakota and defines a major gradient of precipitation that defines differences in western and eastern streams.

The nation includes a wide diversity of landscapes, from the maple-beech-birch forests of the east, to the immense agricultural plains and grasslands of the midwest, to the desert and shrubland of the southwest, to the giant mountain ranges of the west (Figure 1-5). In the eastern part of the country, the Appalachian mountains run from Maine to Alabama, crossing climatic boundaries and separating the waters flowing to the Atlantic from those flowing to the Gulf of Mexico. The larger mountain ranges in the west link their landscapes together: the Rockies through the heart of the West; the Cascades, which crown the Northwest in snow; the Sierra Nevada in California; and the Coastal Range, which plummets to the Pacific with its fault-block shoreline stretching from the Santa Monica mountains to Kodiak Island. The Coastal Plains of the east and southeast and the Great Plains of the interior provide other major land form features that mark the country.

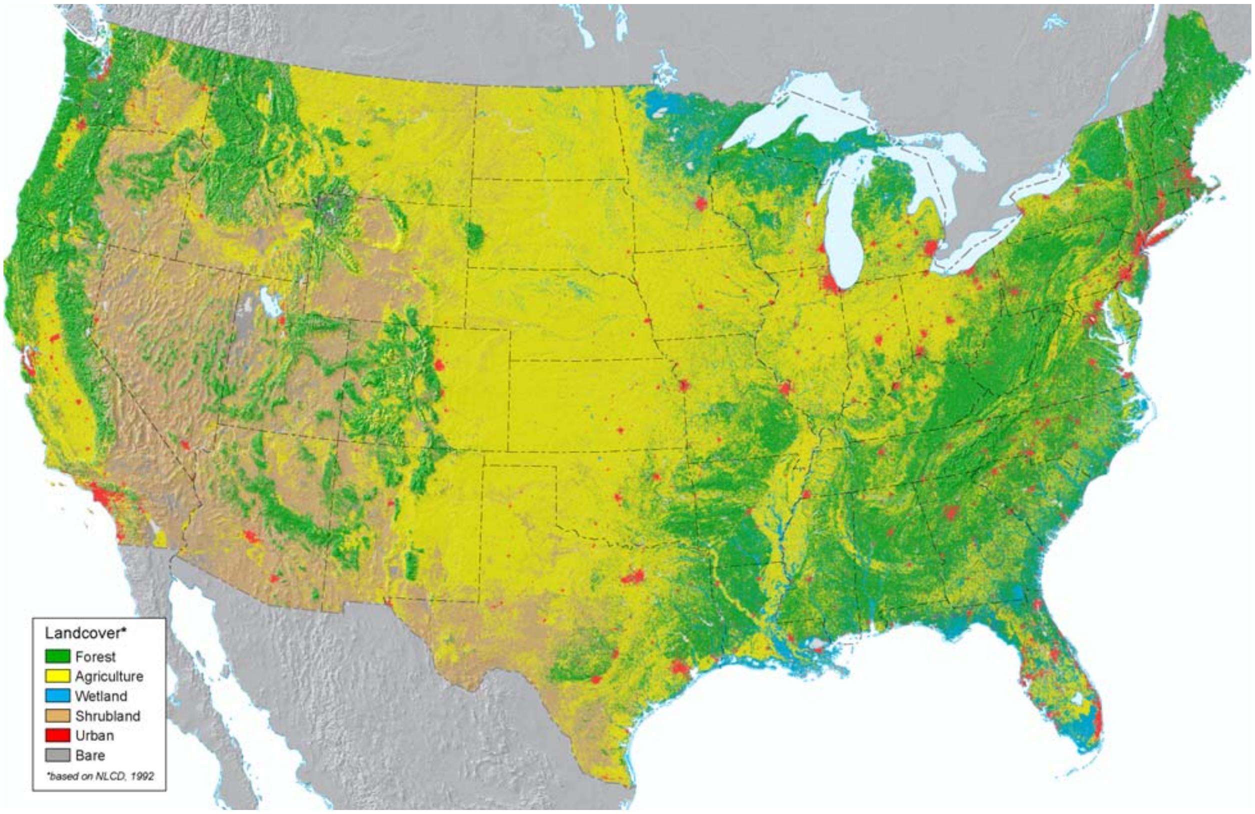


Figure 1-5. The geographic region for WSA and the major landforms and vegetation patterns.

The establishment and spread of European colonies and the Industrial Revolution of the 18th Century intensified the transformation of our natural landscape, as greater numbers of people arrived and modified many of the features of our land and waters. As the nation's population grew and cities and towns were established, tens of thousands of dams were constructed to alter the flow of virtually every major river in the United States.

Historically, people have tended to live where water is more abundant. Current population patterns based on the 2000 U.S. Census reflect the historical abundance of waters in the east and forecast the growing challenges facing the water-scarce regions in the west, where population has grown in recent years (Figure 1-6). The current and future condition of the nation's waters will continue to be influenced by our population patterns and how we use all components of a watershed, including surface water, groundwater, and the land itself.

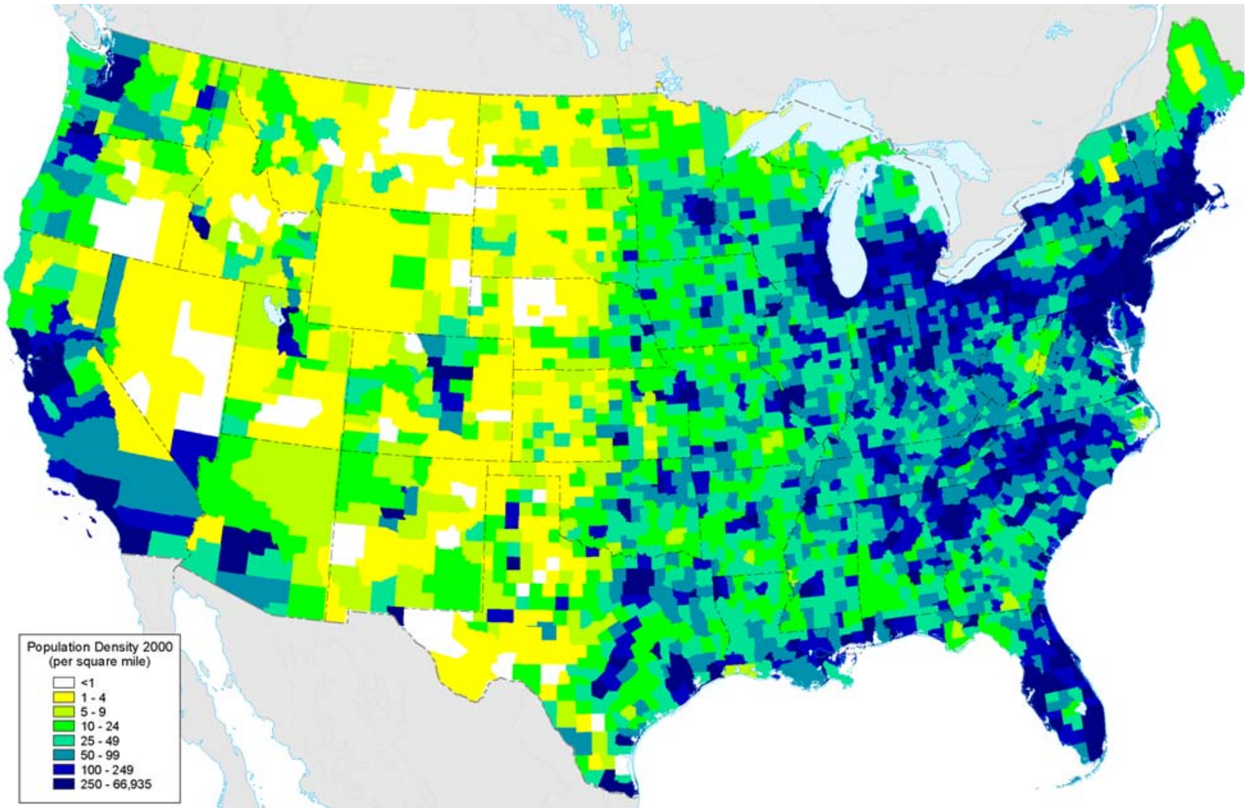


Figure 1-6. Human population density (people per square mile) from the 2000 census.

What regions are used to report WSA results?

The broadest-scale unit for which WSA results are reported is the conterminous United States. For this report, this area has been split into three major regions—the West, the Plains and Lowlands, and the Eastern Highlands—which correspond to the major climate and landform patterns of these areas (Figure 1-7). Chapter 2 of this report describes the results for these broader scale reporting units.

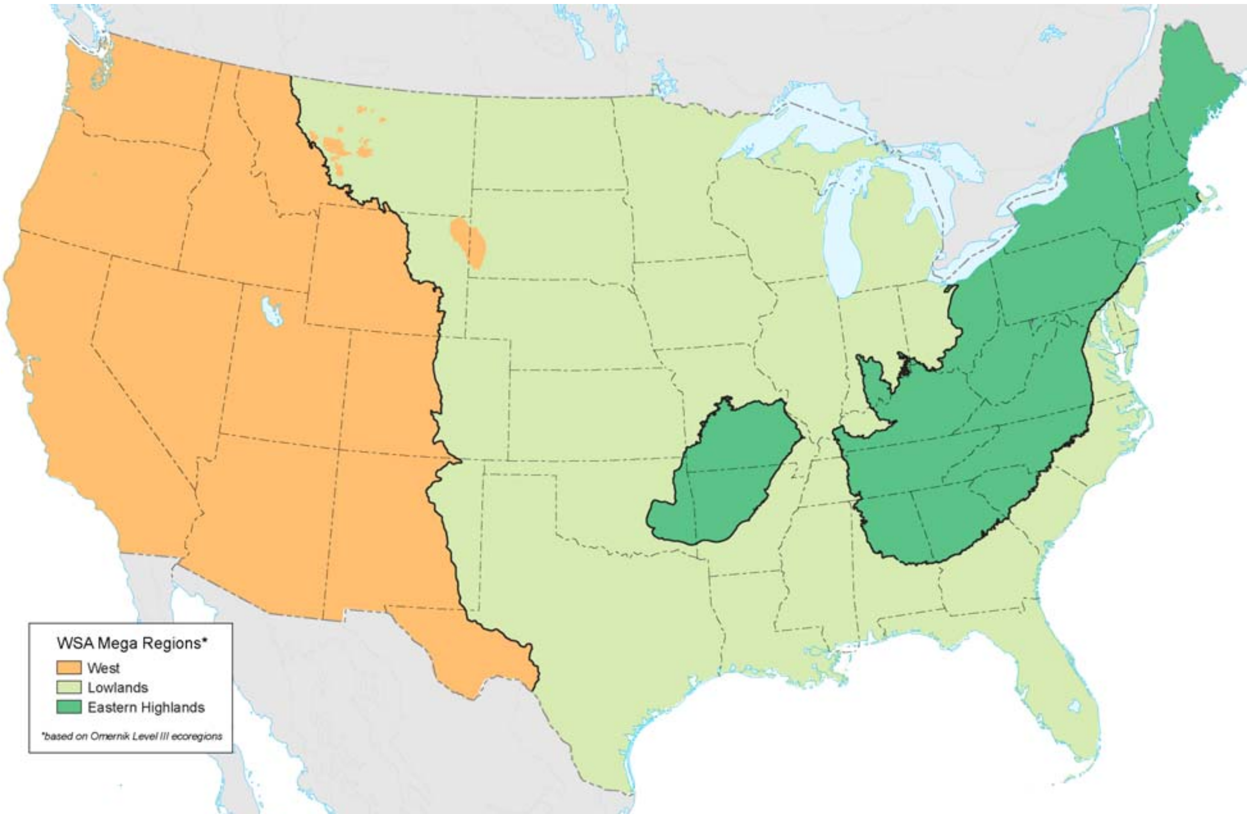


Figure 1-7. Climatic and landform reporting regions for the Wadeable Streams Assessment.

The finest-scale reporting unit included in this WSA consists of nine ecological regions (ecoregions) that further divide the three major regions (Figure 1-8). Ecoregion-specific results are included in Chapter 3 of this report. Some states participating in the WSA opted for an even finer state-scale resolution than the ecoregion scale by sampling additional random sites within their borders. Although these data are included in the analysis described in this report, state-scale results are not presented for each state. The states are preparing similar analyses that reflect their respective water quality standards and regulations.

The Eastern Highlands region is composed of the mountainous areas east of the Mississippi River. It is further divided into two ecoregions: the Northern Appalachians (NAP) ecoregion, which encompasses New England, New York, and northern Pennsylvania, and the Southern Appalachians (SAP) ecoregion, which extends from Pennsylvania into Alabama, through the eastern portion of the Ohio Valley, and includes the Ozark Mountains of Missouri, Arkansas, and Oklahoma.

The Plains and Lowlands region includes five WSA ecoregions: the Coastal Plains (CPL), the Upper Midwest (UMW), the Temperate Plains (TPL), the Northern Plains (NPL) and the Southern Plains (SPL). The Coastal Plains region covers the low-elevation areas of the east and southeast, including the Atlantic and Gulf of Mexico coastal plains and the lowlands of the Mississippi delta, which extend from the Gulf northward through Memphis, Tennessee. The Upper Midwest reflects a region that is dominated by lakes and has little elevation gradient. The Temperate Plains of the midwest are probably most well-known as the Cornbelt. The Northern and Southern Plains are better known as the Great Prairies, with the Northern Plains ecoregion

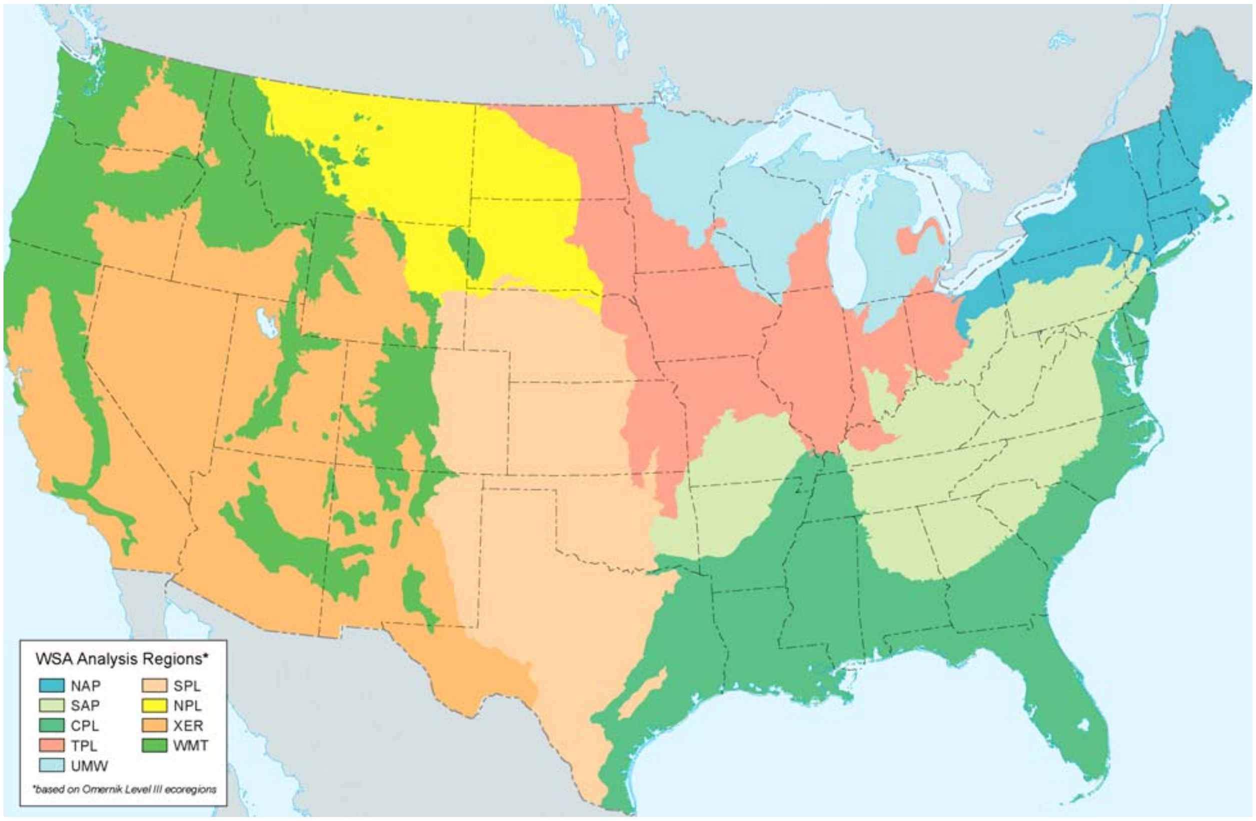


Figure 1-8. Ecological reporting regions for the Wadeable Streams Assessment.

encompassing the Dakotas, Montana, and northeast Wyoming, and the Southern Plains ecoregion encompassing Nebraska, Kansas, Colorado, Oklahoma, and Texas.

The Western region is defined by its Mountainous regions (WMT) and the arid or Xeric region (XER), which includes both the true deserts and the arid lands of the Great Basin.

Landform and climate interact to produce the ecoregions of the United States. Water resources within a particular ecoregion have similar natural characteristics and similar responses to natural and anthropogenic stressors. Typically, management practices aimed at preventing degradation or restoring water quality apply to many flowing waters with similar problems throughout an ecoregion. The WSA uses ecoregions to report results because the patterns of response to stress, and the stressors themselves, are often best understood in a regional context. The three major regions and the nine ecoregions used in this report are aggregations of smaller ecoregions defined by EPA (Omernik, 1987).

How were sampling sites chosen?

The WSA sampling locations were selected using modern survey design approaches. Sample surveys have been used in a variety of fields (e.g., election polls, monthly labor estimates, forest inventory analysis, national wetlands inventory) to determine the status of populations or resources of interest using a representative sample of a relatively few members or sites. This approach is especially cost-effective if the population is so large that all components cannot be sampled or if it is unnecessary to obtain a complete census of the resource to reach the desired level of precision for describing its condition.

As consumers of information, we have all become accustomed to seeing survey data reported in the news. For example, the percentage of children 1–5 years old living in the United States who have high lead levels in their blood is 2.2% +/- 1.2%, an estimate based on a random sample of children in the United States. Results in the WSA have similar rigor in their ability to estimate the percent of stream miles, within a range of certainty, that are in good condition.

To pick a random sample, one must first know the location of members of the population of interest. The target population for the WSA was the perennial wadeable streams in the 1st through 5th Strahler stream order size classes. The WSA design team used the U.S. Geological Survey (USGS) National Hydrography Dataset (NHD)—a comprehensive set of digital spatial data on surface waters at the 1:100K scale— to identify the location of perennial streams. They also obtained information about stream order from the EPA's River Reach File, a related series of hydrologic databases that provide additional attributes about stream reaches. Using these resources, researchers determined the length of wadeable streams in each of the ecological regions (Figure 1-9).

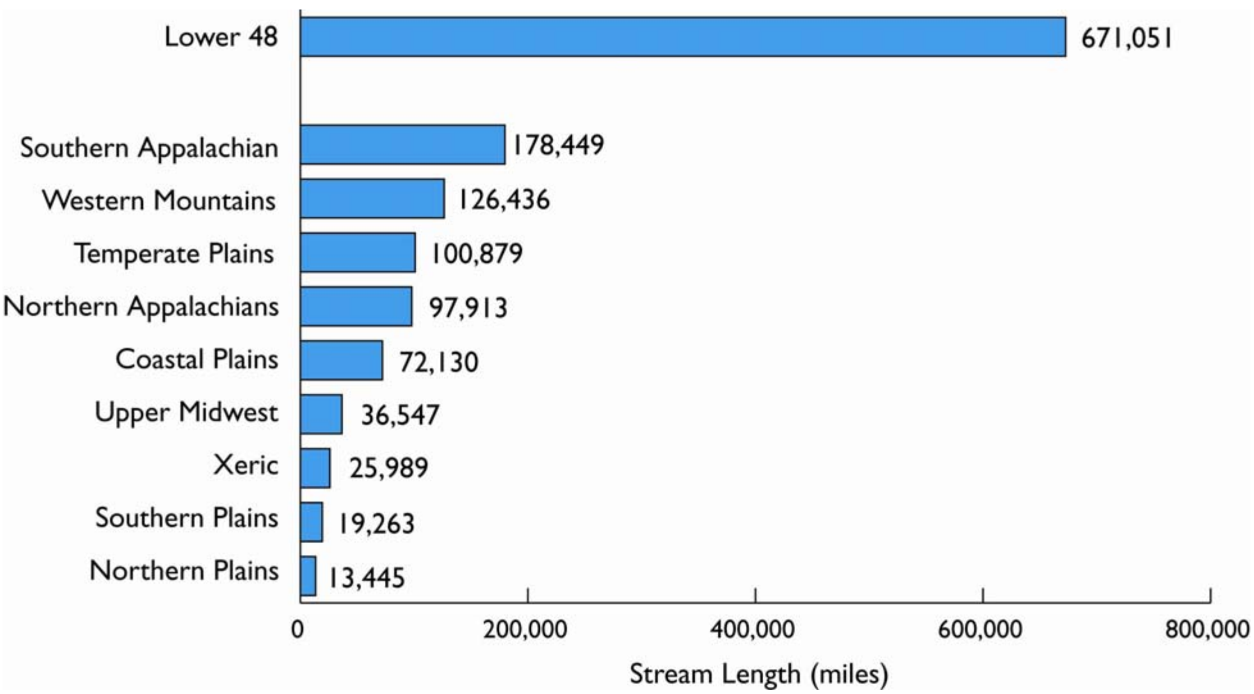


Figure 1-9. Length of wadeable, perennial streams by ecoregion.

The 1,392 sites sampled for the WSA were identified using a particular type of random sampling technique called a probability-based sample design, in which every element in the population has a known probability of being selected for sampling. This important feature ensures that the results of the WSA survey reflected the full range in character and variation among wadeable streams across the United States. Rules for site selection included weighting to provide balance in the number of stream sites from each of the 1st through 5th order size classes and controlled spatial distribution to ensure that sample sites were distributed across the United States (Figure 1-10).

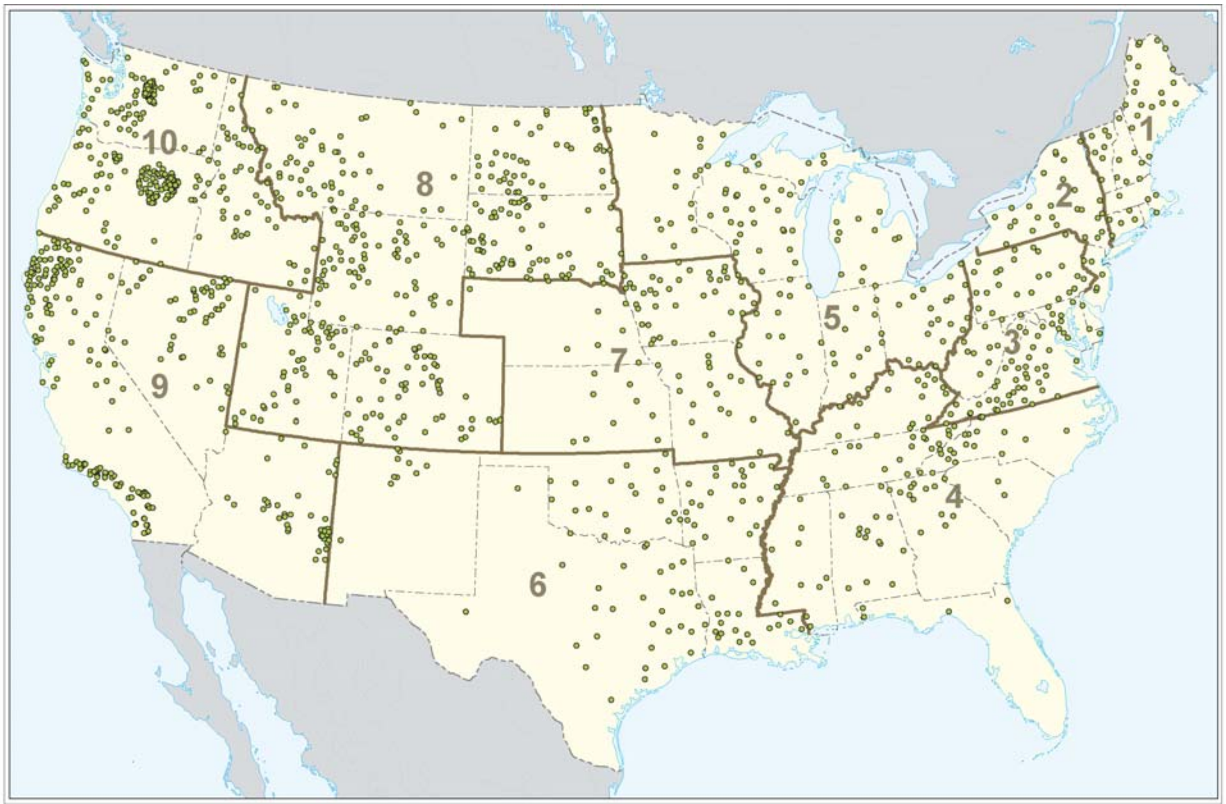


Figure 1-10. Sites sampled for the Wadeable Streams Assessment by EPA Region.

The WSA random sites were allocated by EPA region and by ecological region, based on the distribution of 1st through 5th order streams within those regions. Within each EPA region, the random sites are more densely distributed where the perennial 1st through 5th order streams are more densely located. Sites are more sparsely distributed where streams are sparse. For example, EPA Region 4 includes large portions of the Southern Appalachian and Coastal Plains ecoregions. The random design in EPA Region 4 included greater numbers of sites in the Southern Appalachians because there are more miles of streams there than in the Coastal Plains region (See Figure 1-9).

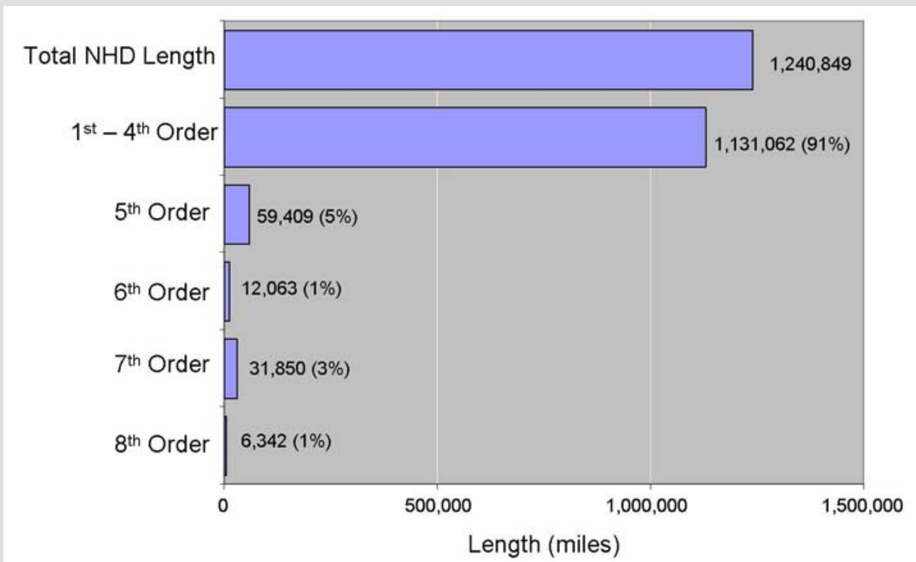
The initial design drew 50 random sites for large-scale ecological regions and EPA regions. An additional 150 reserve replacement sites were generated for each of the EPA regions. These replacement sites were used when site reconnaissance activities documented that one of the original stream sites could not be sampled. Some of the reasons a site was replaced were that the waterbody did not meet the definition of a wadeable stream (e.g., no flowing water over 50% of the reach), was unsafe for sampling, or access was denied by the landowner.

Some of the unusually dense site patterns visible on Figure 1-10 occur because states opted to increase the intensity of random sampling to characterize statewide conditions or specific areas of interest. For example, 15 states increased the number of random sites to support state scale characterizations of stream condition. Additional areas of intensification were added in Washington, Oregon, and California (seen by dense clusters). When sites from an area of intensification are used in the broader scale assessment for a large ecoregion, the weights associated with those sites are adjusted so that those sites do not dominate the ecoregion results.

The survey design and analysis assured that ecological variability present in all wadeable streams and rivers is represented in the assessments.

Highlight: Wadeable Streams Assessment Sampling Frame

perennial stream network contained in the USGS-EPA National Hydrography Dataset (NHD). NHD is a digitized version of 1:100K USGS topographic maps, showing both perennial and non-perennial streams. The total length of the NHD stream and river network labeled perennial in the conterminous United States is 1,204,859 miles. Of this amount, 1,131,062 miles are in 1st through 4th order streams, which make up 91% of the total length of flowing waters, as shown in the following figure. The 1st through 5th order streams are those most likely to be wadeable and form the basis for the target population in WSA.



Estimate of perennial length of streams and rivers from NHD 1st through 4th order streams comprise 91% of total estimated length in the NHD. The 1st through 5th order systems form the basis for the sampling design frame for the WSA.

When sites were selected for sampling in WSA, an office and field reconnaissance was conducted to determine if the streams labeled as perennial in NHD were actually flowing during the sampling season; if they weren't, they would be considered non-perennial, dropped from the sampling effort, and replaced with perennial streams. Other factors were also a basis for not sampling the original selected sites, including field crews being denied permission for access to the site by the landowner; physical barriers to sampling (i.e., inaccessible); or safety concerns for the crews. The decisions on whether a site was non-perennial or inaccessible was determined either in the initial office evaluation, preliminary field evaluation, or by the field crew sent to sample the site. The benefit of conducting a statistically based survey is that, when all of this information is collected and tracked, the results can be applied to the entire population of streams of interest and the total size of each category can be estimated. The results can also be fed back into the NHD so that the system can update the status of the perennial/non-perennial streams information.

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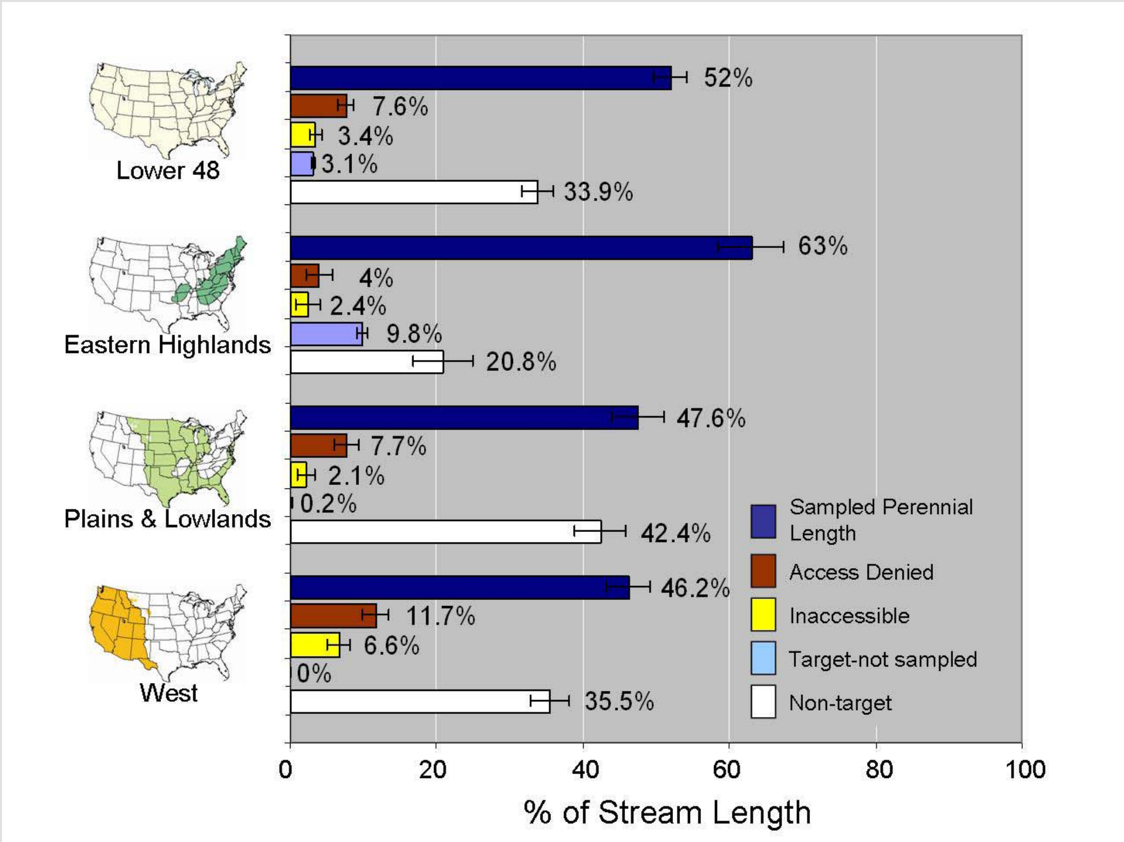

Results of office and field evaluations for the 1st through 4th orders streams in NHD. Percentages represent the percent of the NHD estimates of length that fall into each of the categories.

Of the more than 1 million miles of estimated perennial length, almost 400,000 miles (34%) were found to be non-perennial or non-target in some other way (e.g., wetlands, reservoirs, irrigation canals). The remaining target stream length (780,519 miles) represents the portion of NHD that meets criteria for inclusion in the WSA (perennial, wadeable streams). A portion of the stream length (89,894 miles or 12%) was not accessible to sample because crews were denied access by landowners. An additional portion of the target stream length (40,677 miles or 5%) was physically inaccessible due to physical barriers or other unsafe local conditions.

How were waters assessed?

Each site was sampled by a two- to four-person field crew between 2000 and 2004 during a summer index period. More than 40 trained crews, comprised primarily of state environmental staff, sampled the 1,392 random stream sites using standardized field protocols. The field protocols were designed to consistently collect data relevant to the ecological condition of stream resources and the resources' key stressors.

During each site visit, crews laid out the sample reach and the numerous transects to guide data collection (Figure 1-11). Field crews sent water samples to a laboratory for basic chemical analysis; biological samples, collected from 11 transects along each stream reach, were sent to taxonomists for identification of macroinvertebrates. Crews also completed roughly

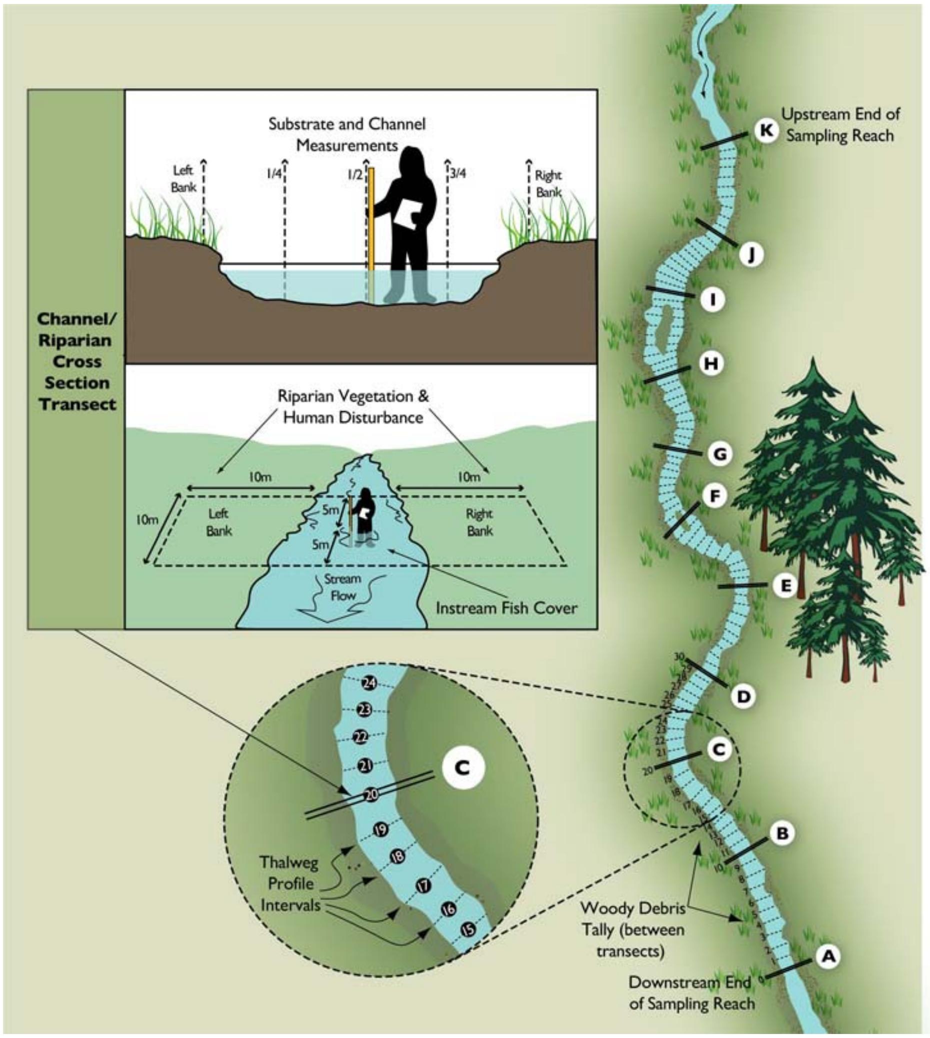

Figure 1-11. Reach layout for sampling.

35 pages of field forms, recording data and information about the physical characteristics of each stream and the riparian area adjacent to its banks. Each crew was audited, and 10% of the sites were revisited as part of the quality assurance plan for the survey.

The use of standardized field and laboratory protocols for sampling is a key feature of the WSA. Because ecologists use a wide range of methods to sample streams, inconsistent results might have arisen from their use in this survey. Standardization allows the data to be combined to produce a nationally-consistent assessment. In fact, this nationwide sampling effort provided an opportunity to examine the comparability of different sample protocols by applying both the WSA method and various state or USGS methods to a subset of the sites. A separate report that examines the comparability of methods and explores options for how data may be used together will be completed later in 2006.

The WSA uses benthic macroinvertebrates as the biological indicator of ecological condition. Benthic macroinvertebrates (e.g., aquatic larval stages of insects, such as dragonfly larvae and aquatic beetles; crustaceans such as crayfish; worms; and mollusks) live throughout the stream bed attached to rocks and woody debris and burrowed in sandy stream bottoms and among the debris, roots, and grasses that collect and grow along the water's edge (Figure 1-12). The WSA focuses on these macroinvertebrates because of their inherent capacity to integrate the effects of the stressors to which they are exposed, in combination and over time. Stream acroinvertebrates generally cannot move very quickly or very far; therefore, they are affected by, and may recover from, a number of changes in physical conditions (e.g., habitat loss), chemical conditions (e.g., excess nutrients), and biological conditions (e.g., the presence of invasive or non-native species). Some types of macroinvertebrates are affected by these conditions more than others.

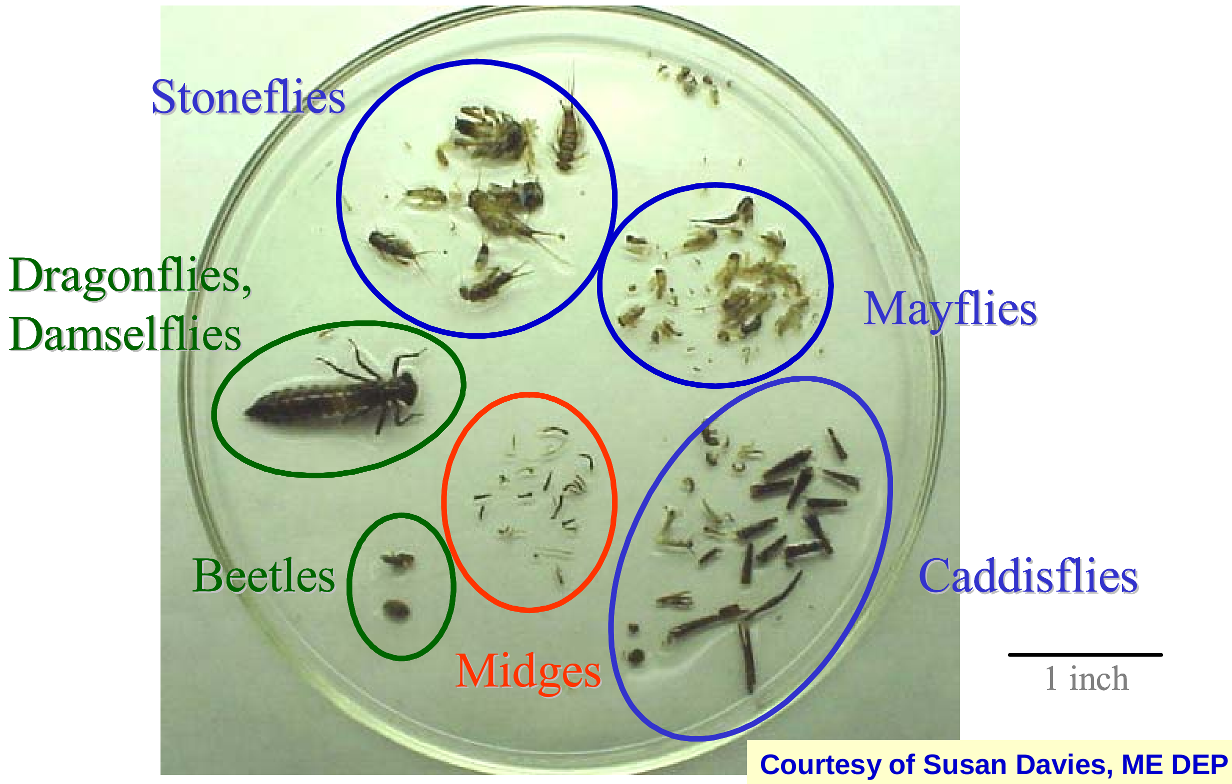

Figure 1-12. Stream macroinvertebrates.

Macroinvertebrates in streams serve as the basis for the indicators of condition for the WSA.

Macroinvertebrates give us a measurement of biological condition or health relative to the biological integrity of a stream. Biological integrity represents the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region. Macroinvertebrates are researched by almost every state and federal program that monitors streams and are also increasingly evaluated by volunteer organizations that monitor water quality. In addition, water quality monitoring and management programs are enhancing the understanding of the biological condition of streams by adding other biological assemblages, including fish and algae.

Highlight: Understanding Biological Condition

The main goal of the WSA is to develop a baseline understanding of the biological condition of our nation's streams. Why is this important?

One of the most meaningful ways to answer basic questions about water quality is to directly observe the communities of plants and animals that live in waterbodies. Aquatic plants and animals—especially the small creatures that are the focus of this study—are constantly exposed to the effects of various stressors; therefore, they reflect not only the current conditions, but also the stresses and changes in conditions over time and the cumulative impacts.

Biological condition is the most comprehensive indicator of waterbody health; when the biology of a stream is healthy, the chemical and physical components of the stream are also typically in good condition.

Data on biological condition are invaluable for managing our aquatic resources and ecosystems. We can use it to set protection and restoration goals, to decide what to monitor and how to interpret what is found, to identify stresses to the waterbody and decide how they should be controlled, and to assess and report on the effectiveness of management actions. In fact, many specific state responsibilities under the CWA—such as determining the extent to which their waters support aquatic life uses, evaluating cumulative impacts from polluted runoff, and determining the effectiveness of discharger permit controls—are tied directly to an understanding of biological condition.

Benthic macroinvertebrates are widely used to determine biological condition. These organisms can be found in all streams, even in the smallest streams that cannot support fish. Because they are relatively stationary and cannot escape pollution, macroinvertebrate communities integrate the effects of stressors over time, i.e., pollution-tolerant species will survive in degraded conditions and pollution-intolerant species will die. These communities are also critically important to fish; most game and non-game species require a good supply of benthic macroinvertebrates as food. Biologists have been studying the health and composition of benthic macroinvertebrate communities in streams for decades.

The WSA supplements information on the biological condition of streams with measurements of key stressors that might negatively influence or affect stream condition. Stressors are the chemical, physical, and biological components of the ecosystem that have the potential to degrade stream biology. Some of these stressors are naturally occurring, and some result only from human activities, but most come from both sources.

Most physical stressors are created when we modify the physical habitat of a stream or its watershed, such as through extensive urban or agricultural development, excessive upland or bank erosion, or loss of streamside trees and vegetation. Examples of chemical stressors include toxic compounds (e.g., heavy metals, pesticides), excess nutrients (e.g., nitrogen and phosphorus), or acidity from acidic deposition or mining. Biological stressors are characteristics of the biota that can influence biological integrity, such as proliferation of non-native or invasive species (either in the streams and rivers, or in the riparian areas adjacent to these waterbodies).

The WSA water chemistry data allow an evaluation of the distribution of nutrients, salinity, and acidification in U.S. streams. The physical habitat data provide information on the prevalence of excess sediments, the quality of in-stream fish habitat, and the quality of riparian habitat alongside streams. Although these stressors are among the key stressors identified by states as affecting water quality, they do not reflect the full range of potential stressors that can impact water quality. Future water quality surveys will include additional stressors.

One of the key components of an ecological assessment is a measure of how important (e.g., how common) each stressor is in a region and how severely it affects biological condition. In addition to looking at the extent of streams affected by key stressors, the WSA evaluated the relative risk posed by key stressors to biological condition.

Setting Expectations

In order to interpret the data collected and to assess current ecological condition, chemical, physical, and biological measurements must be comparable to a benchmark or estimate of what we would expect to find in a natural condition. Setting reasonable expectations for an indicator is one of the greatest challenges to making an assessment of ecological condition. Should we take an historical perspective and try to compare current conditions to an estimate of pre-colonial conditions, pre-industrial conditions, or conditions at some other point in history? Should we accept that some level of anthropogenic disturbance is a given and simply use the best of today's conditions as the benchmark against which everything else is compared?

These questions, and their answers, all relate to the concept of reference condition. What do we use as a reference condition to set the benchmark for assessing the current status of waters? Because of the difficulty of estimating historical conditions for many of our indicators, WSA uses "least-disturbed condition" as the reference condition, which means that the condition represents the best available chemical, physical, and biological habitat conditions given the current state of the landscape. Least-disturbed condition is determined by evaluating data collected at sites selected according to a set of explicit screening thresholds used to define what is in good condition (or least disturbed by human activities). To reflect the natural variability across the American landscape, these thresholds vary from region to region.

The WSA's screening thresholds were developed with the goal of identifying the least amount of ambient human disturbance in each of the nine ecoregions. The WSA uses physical and chemical data collected at each site (e.g., riparian condition, nutrients, chloride, turbidity, excess fine sediments) to determine whether any given site is in least-disturbed condition for its ecoregion. Data on land use in the watersheds is not used for this purpose; for example, sites in agricultural areas may be considered least disturbed, provided they exhibit chemical and physical conditions that are among the best for their region. The WSA also does not use data on biological assemblages to select reference sites; these assemblages are the primary components of the ecosystems for which we need estimates of least-disturbed condition, so to use them would constitute circular reasoning.

For each of the stressor indicators, the WSA used a similar process (i.e., identifying least-disturbed sites according to specific criteria, but excluding the specific stressors themselves from the criteria identifying the sites).

This reference-site approach is used to set expectations and benchmarks for interpreting the data on stream condition. The range of conditions found in the reference sites for an ecoregion describes a distribution of those biological or stressor values expected for the least-disturbed condition. The benchmarks used to define distinct condition classes (e.g., good, fair, poor) are drawn from this reference distribution. At a national meeting to discuss data analysis options, the WSA collaborators supported this reference condition-based approach, which is consistent with EPA guidance and state practice on the development of biological and nutrient criteria.

The WSA's approach examined the range of values for a biological or stressor indicator in all of the reference sites in a region and used the 5th percentile of the reference distribution for that indicator to separate the poor sites from fair sites. Using the 5th percentile means that stream sites and associated miles in the poor category were worse than the best 95% of the least-disturbed sites used to define reference condition. Similarly, the 25th percentile of the reference distribution was used to distinguish between fair sites and those in good condition. This means that stream miles reported as being in good condition were as good as or better than the best 75% of the least-disturbed sites used to define reference condition.

Within the reference site population, there exist two sources of variability: natural variability and variability due to human activities. The wide range of habitat types naturally found within each ecoregion creates a spread of reference sites representing these differing habitats. Capturing this natural diversity in reference sites helps establish reference conditions that represent the range of environments in the ecoregions.

The second source of variation within the reference population are changes resulting from human activites. Many areas in the U.S. have been altered, and their natural landscapes transformed with cities, suburban sprawl, agricultural development, and resource extraction. The extent of those disturbances varies across regions. Some of the regions of the country have reference sites in watersheds with little to no evidence of human impact. These can be streams in the mountains or in areas with very low population densities. Other regions of the country have few sites that have not been influenced by human activities. Within these regions, the least-disturbed reference sites displayed more variability in quality than areas where the least-disturbed reference sites were in watersheds with little human disturbance.

Variation within the reference distribution due to disturbance was addressed before setting benchmarks for the condition classes of good, fair, and poor. For regions where the reference sites exhibited a disturbance signal, the data analysis team accounted for this disturbance by shifting the mean of the distribution toward the less disturbed of the reference sites. Additional details on how least-disturbed condition and benchmarks for the condition categories were set for the WSA can be found in Appendix A at the back of this report.